

Lecture Module - Strain Gauges

ME3023 - Measurements in Mechanical Systems

Mechanical Engineering

Tennessee Technological University

Module 9 - Strain Gauges

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- Topic 1 - Measuring Strain
- Topic 2 - The Wheatstone Bridge
- Topic 3 - P3 Strain Indicator

Topic 1 - Measuring Strain

- Motivation in Design
- Stress and Strain
- The Strain Gauge
- Engineering Applications

Motivation in Design

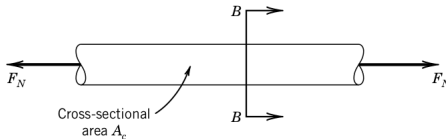
The design of load-carrying components for machines and structures requires information concerning the **distribution of forces within the particular component**. Proper design of devices such as shafts, pressure vessels, and support structures must consider **load-carrying capacity and allowable deflections**. Mechanics of materials provides a basis for predicting these essential characteristics of a mechanical design, and provides the fundamental understanding of the behavior of load-carrying parts. However, theoretical analysis is often not sufficient, and **experimental measurements** are required to achieve a final design.

Text: Theory and Design of Mechanical Measurements

Motivation in Design

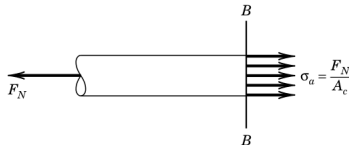
Stress and Strain

Consider a member under uni-axial loading. The **strain** is defined as the ratio of the change in length to the original length of the component.



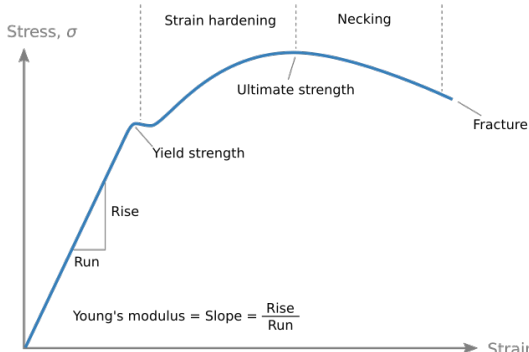
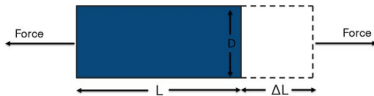
$$\sigma_a = \frac{F_N}{A_c}$$

$$\epsilon_a = \frac{\delta L}{L}$$



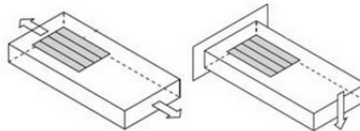
$$\sigma_a = E_m \epsilon_a$$

Stress and Strain



The Strain Gauge

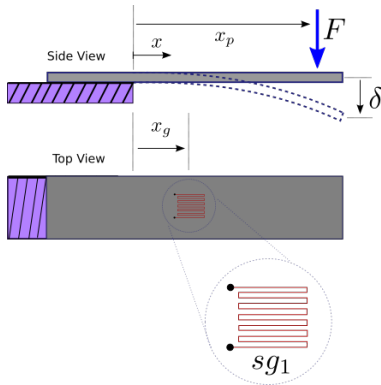
... the ideal sensor for the measurement of strain would (1) have good spatial resolution, implying that the sensor would measure strain at a point; (2) be unaffected by changes in ambient conditions; and (3) have a high-frequency response for dynamic (time-resolved) strain measurements. A sensor that closely meets these characteristics is the **bonded resistance strain gauge**.



Text: Theory and Design of Mechanical Measurements

The Strain Gauge

Strain gauges can be mounted in different ways for different purposes. We will begin with a single gauge mounted in the axial direction.



Engineering Applications

- Segway back to *Motivation in Design* (Slide 1) ...
- Aerospace
- Infrastructure
- Short article on applications [here](#).

Engineering Applications

Engineering Applications

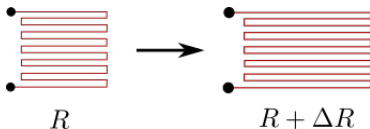
Topic 2 - The Wheatstone Bridge

- Resistive Gauges
- The Bridge Circuit
- Balancing the Bridge
- Gauge Sensitivity

Resistive Gauges

The resistive strain gauge, aka *metallic gauge*, is bonded to the surface so that it deforms with the specimen. The change in length of the bonded gauge causes a change in resistance which is used as a measure of strain.

$$R = \rho_e L / A_c = fn(L, \dots)$$



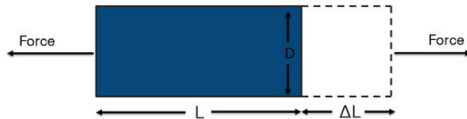
This is an exaggerated picture so the change is very small...

Resistive Gauges

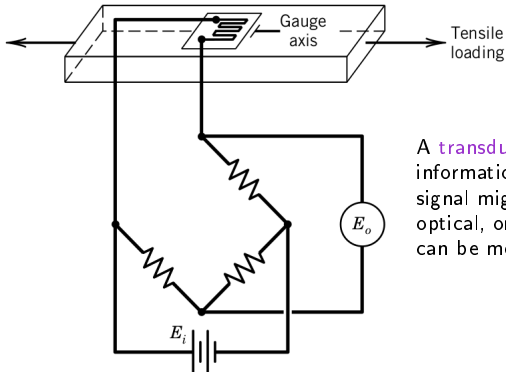
The **Gauge Factor** is typically used instead of the physical parameters.

$$GF \equiv \frac{\delta R/R}{\delta L/L} = \frac{\delta R/R}{\epsilon_a}$$

This number relates the relative change in resistance to the measured strain.

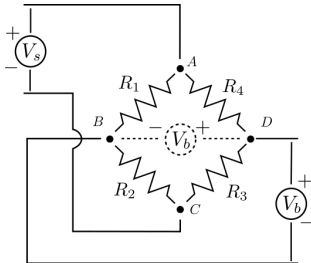


The Bridge Circuit



A **transducer** converts the sensed information into a detectable signal. The signal might be mechanical, electrical, optical, or may take any other form that can be meaningfully recorded.

The Bridge Circuit



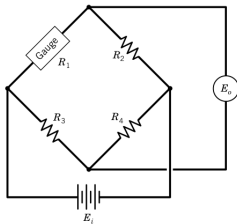
How does the bridge circuit work as a transducer?

Use KVL and the voltage divider rule find the relationship between the two voltages.

$$V_b = \left(\frac{R_3}{R_3 + R_4} - \frac{R_2}{R_1 + R_2} \right) \times V_s$$

Balancing the Bridge

If all four resistors are equal the bridge voltage will equal zero and the bridge is said to be **balanced**. One or more resistors in the circuit is replaced by a strain gauge and bridge voltage is used as a measure of change in resistance and therefore strain.

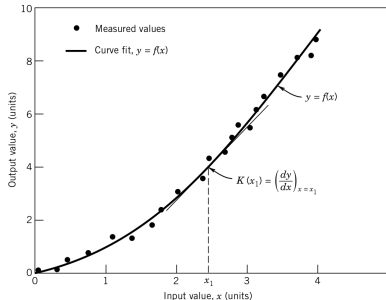


This gives a linear **calibration curve** with a convenient **zero offset**.

Balancing the Bridge

Balancing the Bridge

Gauge Sensitivity



Assume $R = 120\Omega$ for all resistors and the bridge is balanced in a condition of zero strain. What is the **static sensitivity** of the gauge and bridge circuit described?

$K =$

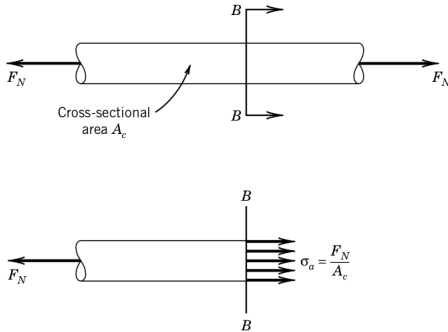
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Gauge Sensitivity

Topic 3 - P3 Strain Indicator

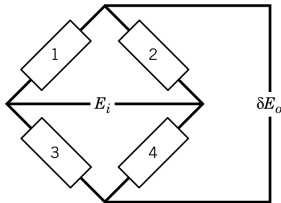
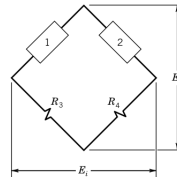
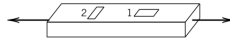
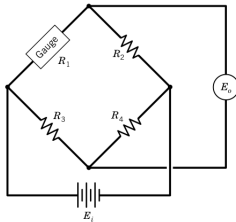
- Units of Microstrain
- Quarter, Half, and Full Configurations
- Operating the P3
- Alternative Solutions
- Alternative Solutions

Units of Microstrain

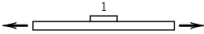
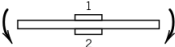
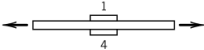
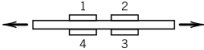
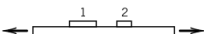
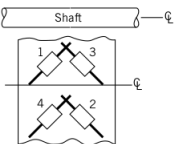


Units of Microstrain

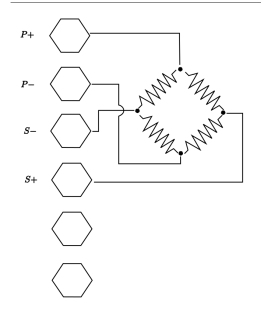
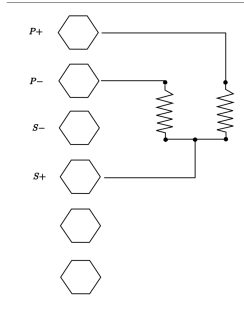
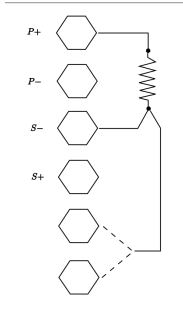
Quarter, Half, and Full Configurations



Quarter, Half, and Full Configurations

	Arrangement	Compensation Provided	Bridge Constant κ
	Single gauge in uniaxial stress	None	$\kappa = 1$
	Two gauges sensing equal and opposite strain—typical bending arrangement	Temperature	$\kappa = 2$
	Two gauges in uniaxial stress	Bending only	$\kappa = 2$
	Four gauges with pairs sensing equal and opposite strains	Temperature and bending	$\kappa = 4$
	One axial gauge and one Poisson gauge		$\kappa = 1 + \nu$
	Four gauges with pairs sensing equal and opposite strains—sensitive to torsion only; typical shaft arrangement.	Temperature and axial	$\kappa = 4$

Operating the P3



Operating the P3

Operating the P3

- The instructions are on the unit.
- The balancing process is completed after changing any wiring.



Operating the P3

Alternative Solutions

- The P3500/P3 is expensive, but it is a reliable instrument. The ME department has used them for years with success.
- The manufacturer *Vishay Group* has a *more* modern solution with DAQ and multiple channels.
- There are a variety of low cost alternative options available.
 - [Sparkfun - strain gauge basics](#)
 - [Robot Shop](#)
 - [elecrow](#)